



UM10813

SSL5301DB1204 120 V 36 W fixtures, isolated high PF mains dimmable LED driver demo board

Rev. 1.1 — 15 October 2014

User manual

Document information

Info	Content
Keywords	SSL5301DB1204, SSL5301T, flyback converter, high Power Factor (PF), high efficiency, low Total Harmonic Distortion (THD), 120 V mains, main phase-cut dimmable
Abstract	This document describes the operation of the SSL5301DB1204 36 W LED driver demo board featuring SSL5301T and using an isolated flyback topology. The demo board is designed for mains phase-cut dimmable applications used in Solid-State Lighting (SSL) applications.



Revision history

Rev	Date	Description
v.1.1	20141015	updated version
v.1	20140820	first issue

Contact information

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1. Introduction

WARNING

Lethal voltage and fire ignition hazard



The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

This user manual describes the operation of the SSL5301DB1204 36 W isolated flyback converter driver demo board featuring the SSL5301T. The demo board is designed for 120 V mains phase-cut dimmable applications.

The SSL5301DB1204 demo board is designed for 48 V at a 700 mA LED string load.

The single layer PCB with dimensions 120 mm × 50 mm × 30 mm is intended for fixtures used in SSL applications.

The SSL5301DB1204 demo board provides a simple and effective solution for a 120 V mains application. It includes a high Power Factor (PF), high efficiency, and a low Total Harmonic Distortion (THD).

The topology uses a single stage flyback converter without Power Factor Correction (PFC) pre-stage.

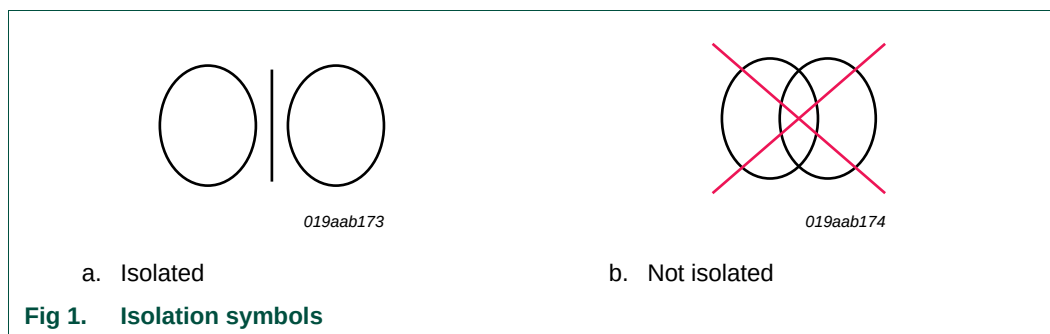
1.1 Features

- SSL5301T LED driver
- Single stage flyback converter without PFC pre-stage
- 120 V mains phase-cut dimmable for Leading-Edge (LE), Trailing-Edge (TE) and smart dimmers
- Open LED string protection
- Short circuit LED string protection
- OverCurrent Protection (OCP)
- OverTemperature Protection (OTP)
- Power factor > 0.95
- THD < 10 %
- Efficiency > 88 %
- Compliant with IEC61000-3-2 harmonics standard
- Compliant with FCC15 EMC standard

[Figure 2](#) shows the assembled top and bottom board views.

2. Safety warning

The board must be connected to mains voltage. Avoid touching the demo board while it is connected to the mains voltage. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation of the mains phase using a variable transformer is always recommended. [Figure 1](#) shows the symbols that identify the isolated and non-isolated devices.



3. Specifications

Table 1. SSL5301DB1204 demo board specifications

Symbol	Parameter	Value
V_{mains}	AC mains voltage supply	120 V (AC); $\pm 10\%$
P_i	nominal input power	37 W
P_o	nominal output power	32.5 W
V_{LED}	output voltage (LED voltage)	48 V (range is 38 V to 52 V)
I_{LED}	output current (LED current)	675 mA to 725 mA (nominal 700 mA)
I_{ripple}	output ripple current	$\pm 30\%$
$\Delta I_{\text{LED}}/\Delta V_{\text{mains}}$	line regulation	$< 0.5\%$ for $\Delta V_{\text{mains}} = 120\text{ V}; \pm 10\%$
$\Delta I_{\text{LED}}/\Delta V_{\text{LED}}$	load regulation	$< 2\text{ mA/V}$
η	efficiency	$> 88\%$
PF	power factor	> 0.99
THD	total harmonic distortion	$< 10\%$
f_{sw}	switching frequency	45 kHz
PCB dimensions	L × W × H	120 mm × 50 mm × 30 mm
OVP ^[1]	OverVoltage Protection (OVP) or Open String Protection (OSP)	$V_{\text{LED}} > 55\text{ V}$
OSP ^[2]	Output Short Protection	$V_{\text{LED}} = 0\text{ V}$

[1] OVP is a latched protection. It is valid during start-up or during operation when no LEDs are connected.

[2] OSP is valid if an output short event of the LEDs occurs during start-up or during operation.

4. Board photographs



aaa-014444

a. Top view



aaa-014445

b. Bottom view

Fig 2. SSL5301DB1204 36 W panel demo board

5. Board connections

The SSL5301DB1204 demo board is supplied using 120 V mains voltage. [Figure 3](#) shows the board connections.

Table 2. Input and output connections
[Figure 8](#) (top view) shows the connectors.

Connector	Function	Comment
X9	120 V mains input	live and neutral between pins 1 and 2 of X9
J1	LED load	pin 1 of J1 to + LED load pin 2 of J1 to - LED load
S2	For measurement purposes only (option 1)	during measurements on the demo board using oscilloscope probes, connect 10 V to pin 2 of S2. Short pins 2 and 3 of S3
S3	For measurement purposes only (option 2)	during measurements on the demo board using oscilloscope probes, short pins 1 and 2 of S3

Remarks:

- Make all connections with the input mains supply switched off.
- Use a protective shield over the application. Never touch the board when measuring or testing.

Connections and testing:

- Connect a 16-LED string load to J1 of the SSL5301DB1204 demo board. Connect a power meter at both the X9 input and the J1 output.
- Connect the 120 V mains to the input connection points of the flyback converter using an isolating transformer (initially set to 0 V). Alternatively, use an AC power supply with limited output current capability (for example, 500 mA).
- Set V_{mains} to the voltages as indicated in [Table 3](#).

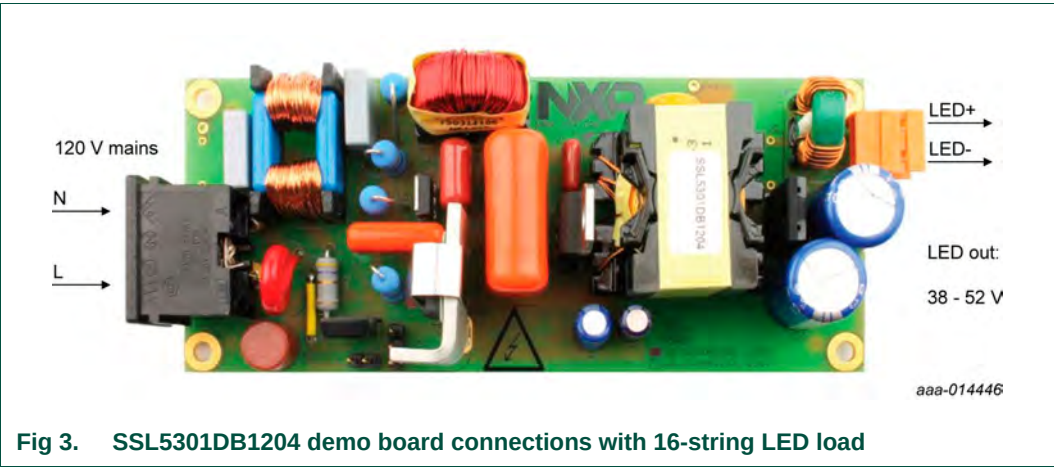


Fig 3. SSL5301DB1204 demo board connections with 16-string LED load

6. Functional description

6.1 Input filtering

Common-mode and differential mode filters are implemented to reduce common-mode or differential mode noise (see [Figure 7](#)). This noise originates from the HF switching currents/voltages in the primary side of the converter from returning to the mains. The common-mode filter is L5 (or L2), C14 and C34. The differential mode filter is L1 (including leakage of L5), C2, C3, C8, and C9. The noise is also kept to a minimum by:

- Small primary current loop from C2 to pin 1 of T1, pin 3 of T1 to the drain of external MOSFET Q1. Ground return from sense resistors R1, R2 back to ground of C2.
- Snubber components D3, R6, R46 and C1 closely parallel to pins 1 and 3 of T1
- To reduce capacitance to surroundings, the track length from pin 3 of T1 to the drain of the external MOSFET must be small.
- Small secondary current loop from pin 10 of T1 to D19 and C10 and returning to pin 9 of T1

For the 36 W application, the value of capacitor C2 must be high enough to act as a buffer for the HF currents flowing in the primary side through L_p of T1. It must be low enough to maintain a high PF. A value of 470 nF gives good results.

6.2 R_{mains} detection (RMAINS pin)

The SSL5301T uses a detection level of 20 μA to detect mains zero crossing. The input current from the mains is derived from the mains input voltage via resistors R13, R14, R15, R44 and R45.

For 120 V mains detection at maximum input mains, the resistor values are:

- R13, R14, and R15: 150 k Ω
- R44 and R45: 0 Ω

The resulting mains zero crossing detection is: $(150 \text{ k}\Omega \parallel 150 \text{ k}\Omega + 150 \text{ k}\Omega) \cdot 20 \mu\text{A}$.

To remove unwanted noise at low input voltage levels, extra external filtering on the RMAINS pin is realized with C7 = 220 pF.

To prevent non-detection of the zero crossing, an additional circuit on the mains input is included. However, this circuit is only required if measurements are carried out on the demo board using oscilloscope probes. The circuit is comprised of diodes D7 and D8, resistors R16, R17, R18, and R69, capacitor C6, and transistor Q2. It is operational if 5 V to 10 V is supplied externally to header S2 (with pins 2 and 3 of S3 shorted). It is also operational when pins 1 and 2 of S3 are shorted.

6.3 Supply voltage

The SSL5301T supply voltage (V_{CC}) is generated using an auxiliary winding, a 24 V Zener diode (D27), and transistor Q6.

OverVoltage Protection (OVP) is a latched protection. It is reached at a minimum supply voltage of 28 V at the V_{CC} pin, which corresponds to a 52 V LED voltage.

UnderVoltage LockOut (UVLO) is reached when $V_{CC} < V_{CC(stop)}$ (maximum 10 V).

6.4 Charge pump and filter damping

The charge pump capacitor C38 is connected to the drain of MOSFET Q1. When Q1 switches off, capacitor C37 is charged using D21. Capacitor C37 and resistor R56 determine the time constant. The values of R56 and C37 are selected, so a time constant of 700 μ s is achieved. This time constant is required to latch a Leading-Edge (LE) triac dimmer correctly. When Q1 switches on, the charge return through C38 is via D22.

The MOSFET Q4 conducts when the voltage on capacitor C37 exceeds the gate Q4 threshold voltage (10 V). The damping resistance is $R55 = 4.7 \Omega$ in series with R_{DSon} of Q4 (0.5 Ω). This total resistance is small to maintain high efficiency.

When MOSFET Q4 is not conducting (e.g. during zero crossings of the mains or when an LE triac dimmer switches on), resistors R53 and R54 determine the series damping (totaling 112 Ω (or $2 \times 56 \Omega$)). This relatively high value of resistance is required to limit inrush current. It is also required to dampen the ringing of the differential mode filter.

6.5 RC damper and bleeding circuit

To ensure that sufficient current is flowing through the LE triac dimmer when the dimmer switches on, resistors R49 and R50 and capacitor C36 are required. After the LE triac dimmer has latched and is conducting, the total of the bleeder current + the converter current is sensed across resistors R66 and R68. $R63 / (R63 + R64)$ attenuates the voltage across $R66 // R68$ which is supplied to the BLS pin. This voltage is controlled to the regulation voltage $V_{th(reg)BLS}$. In this way, the total of the bleeder current and the converter current is kept constant. To ensure its conduction throughout the dimming range, this current is set greater than the hold current of the triac dimmer. Capacitor C39 ensures that the regulation loop is fast, especially at low dimming levels.

To achieve a similar power distribution across $R51 + R52$ and MOSFET Q3, the bleeder resistors R51 and R52 are 390 Ω .

6.6 Output capacitor and filtering

A provision for RC snubber across the secondary diode has been made on Printed-Circuit Board (PCB).

The RC snubber is not mounted on the SSL5301DB1204 demo board, because it is not required for this board. If necessary, it can improve the high-frequency EMI performance. However, depending on the values chosen for resistors R42 and R48 and capacitor C35, the overall system efficiency decreases.

To get $I_{ripple} < 30 \%$, output capacitors C10 and C11 (470 μ F) are chosen. When capacitors C10 and C11 are $2 \times 1000 \mu$ F, the ripple can be decreased to $< 15 \%$.

When the demo board is not operational, resistor R41 discharges capacitors C10 and C11.

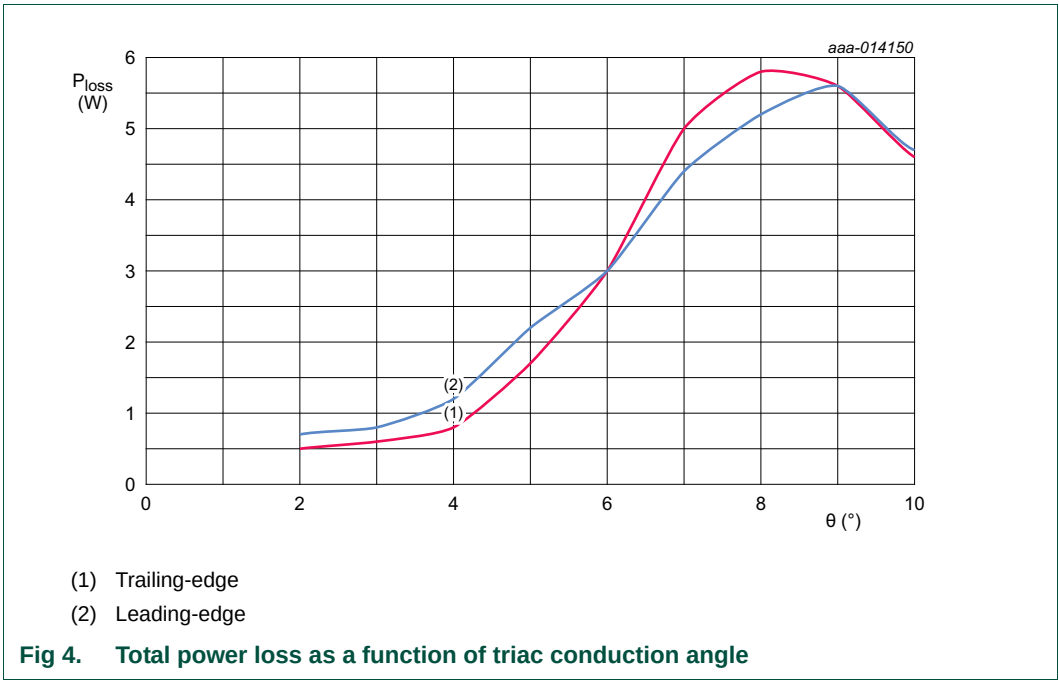
Extra differential and common-mode filtering at the LED output is realized using inductor L3 and capacitors C12 and C13.

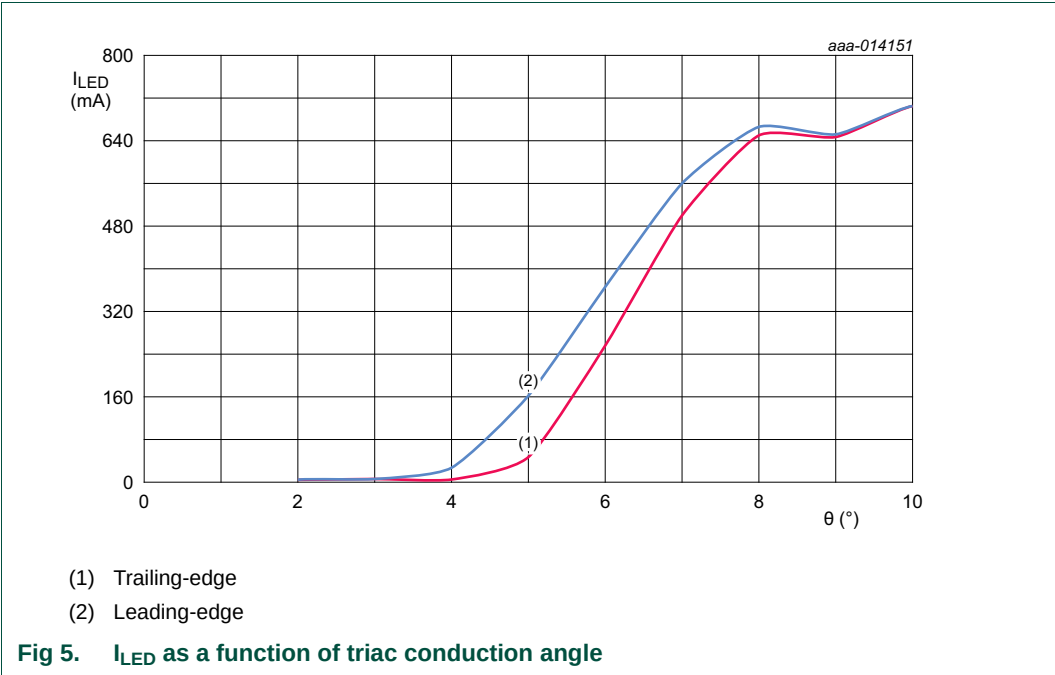
7. Performance

Table 3. Parameters of SSL5301DB1204 demo board as a function of V_{mains}

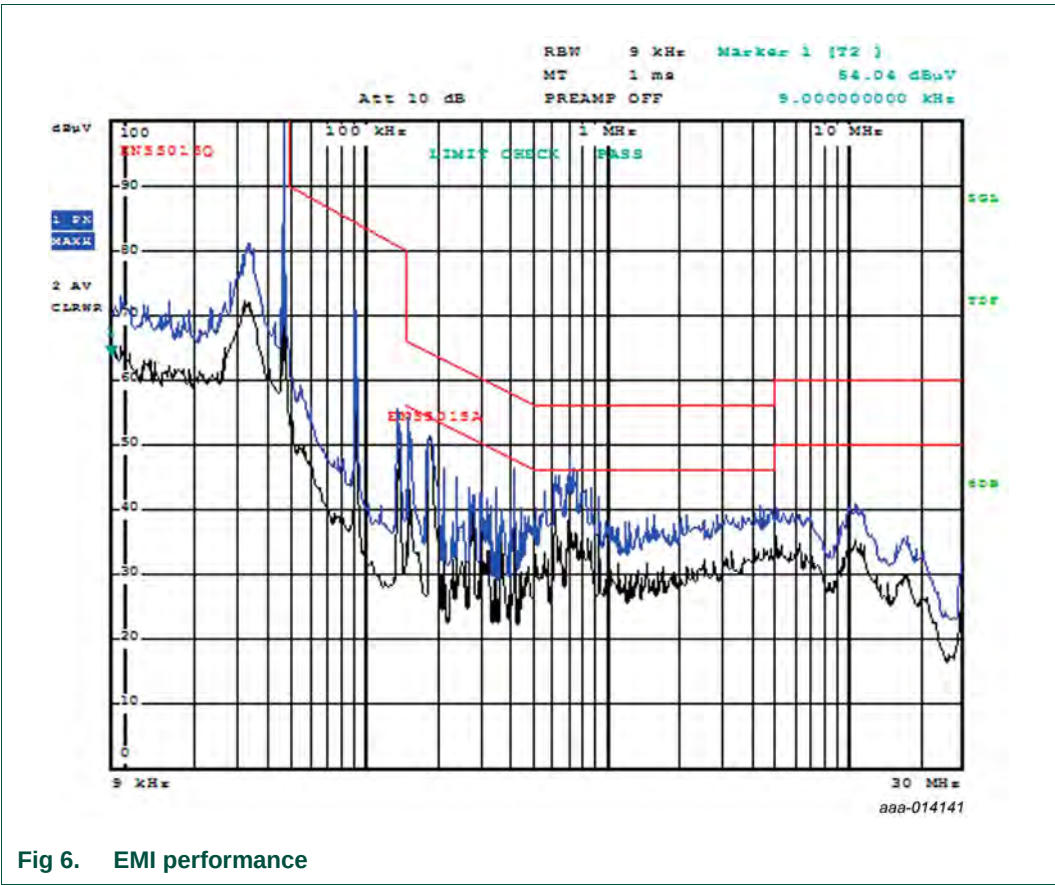
V_{mains} (V)	I_{mains} (mA)	P_i (W)	V_{LED} (V)	I_{LED} (mA)	P_{LED} (W)	PF	THD (%)	η (%)
108	350	37	47	705	32.5	0.99	9	88
120	312	37	47	707	32.5	0.99	8	88
132	280	37	47	708	32.5	0.99	7	88

7.1 Power losses





7.2 ElectroMagnetic Interference (EMI)



7.3 Dimmer performance

Table 4. SSL5301DB1204 dimmer performance

Dimmer type	I _{LED} (minimum dim level) (mA)	I _{LED} (maximum dim level) (mA)
Cooper 6B28	6	650
CTCL-153P-WH	5.5	600
GE-18020	50	648
GE-18025	65	646
GE-52159	65	645
Lutron 6B38	35	610
Lutron D600PHD	45	590
Lutron LG-600P	3.5	638
Lutron LG-600PH-IV	3.5	642
Lutron S36	3	645
Lutron S-600P	3	645
Lutron S-600PH	3.5	645
Lutron S600PR IV	3.5	643
Lutron T9	3.5	650
Leviton 663	50	645
Leviton 6631	3.5	650
Leviton 6681	3	650
Leviton 6682	50	650
Leviton 6842	65	645
Leviton 898F	50	646
Niko 310-0190X (TE)	3	645

The dimmer performance is smooth with the dimmers tested in [Table 4](#).

The minimum dimming level is < 0.5 %.

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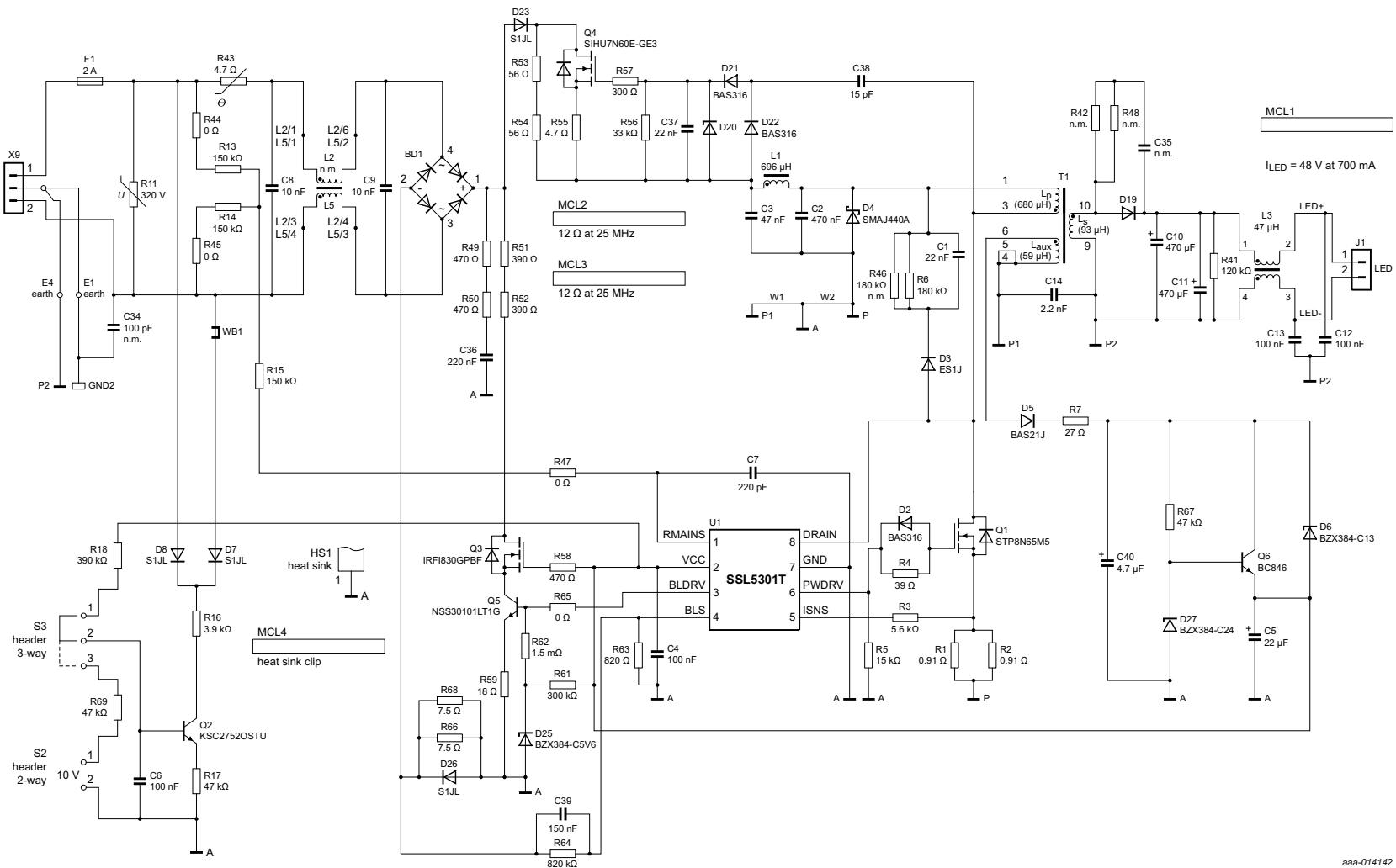


Fig 7. SSL5301DB1204 schematic diagram

9. Bill Of Materials (BOM)

Table 5. SSL5301DB1204 demo board bill of materials

Reference	Description and values	Part number	Manufacturer
BD1	bridge rectifier; 600 V; 800 mA	B6S-G	Comchip Tech
C1	capacitor; 22 nF; 5 %; 250 V; PET; THT	ECQE2223JF	Panasonic
C2	capacitor; 470 nF; 10 %; 630 V; PET; THT	BFC246840474	Vishay
C3	capacitor; 47 nF; 5 %; 630 V; PET; THT	ECQE6473JF	Panasonic
C4; C6	capacitor; 100 nF; 10 %; 50 V; X7R; 0603	C0603C104K5RACTU	KEMET
C5	capacitor; 22 μ F; 20 %; 50 V; ALU; THT	ECA1HAK220X	Panasonic
C7	capacitor; 220 pF; 10 %; 50 V; X7R; 0805	CC0805KRX7R9BB221	Yageo
C8; C9	capacitor; 10 nF; 20 %; 275 V (AC); polypropylene; X2	BFC233620103	EPCOS
C10; C11	capacitor; 470 μ F; 20 %; 63 V; ALU; lead spacing = 12.5 mm; height = 20 mm	ECA1JAM471X	Panasonic
C12; C13	capacitor; 100 nF; 10 %; 100 V; X7R; 0603	GRM188R72A104KA35D	Murata
C14	capacitor; 2.2 nF; 20 %; 300 V; VY2; THT	VY2222M35Y5US6TV7	Vishay
C34	capacitor; not mounted; 100 pF; 10 %; 300 V (AC); Y5S; THT	VY2101K29Y5SG63V7	Vishay
C35	capacitor; not mounted	-	-
C36	capacitor; 220 nF; 10 %; 400 V; PET; THT	BFC236855104	Vishay
C37	capacitor; 22 nF; 10 %; 50 V; X7R; 0603	CC0603KRX7R9BB223	Yageo
C38	capacitor; 15 pF; 10 %; 630 V; C0G; 1206	GRM31A5C2J150JW01D	Murata
C39	capacitor; 150 nF; 10 %; 50 V; X7R; 0603	C0603C154K5RACTU	KEMET
D2	diode; 100 V; 250 mA; SOD-323	BAS316	NXP Semiconductors
D3	diode; 600 V; 1 A; DO-214AC	ES1J	Fairchild
D4	diode; TVS; unidirectional; 440 V; 600 mA; DO-214AC; SMA	SMAJ440A	Littelfuse
D5	diode; 300 V; 250 mA; SOD-323F	BAS21J	NXP Semiconductors
D6	diode; Zener; 13 V; 200 mA; SOD-323	BZX384-C13	NXP Semiconductors
D7; D8; D23; D26	diode; 600 V; 1 A; SMF	S1JL	Taiwan Semiconductor
D19	diode; 200 V; 8 A; TO-220F	BYW29EX-200	NXP Semiconductors
D20	diode; Zener; 10 V; 200 mA	BZX384-C10	NXP Semiconductors
D21; D22	diode; 100 V; 250 mA	BAS316	NXP Semiconductors
D25	diode; Zener; 5.6 V; 200 mA	BZX384-C5V6	NXP Semiconductors
D27	diode; Zener; 24 V; 200 mA	BZX384-C24	NXP Semiconductors

Table 5. SSL5301DB1204 demo board bill of materials

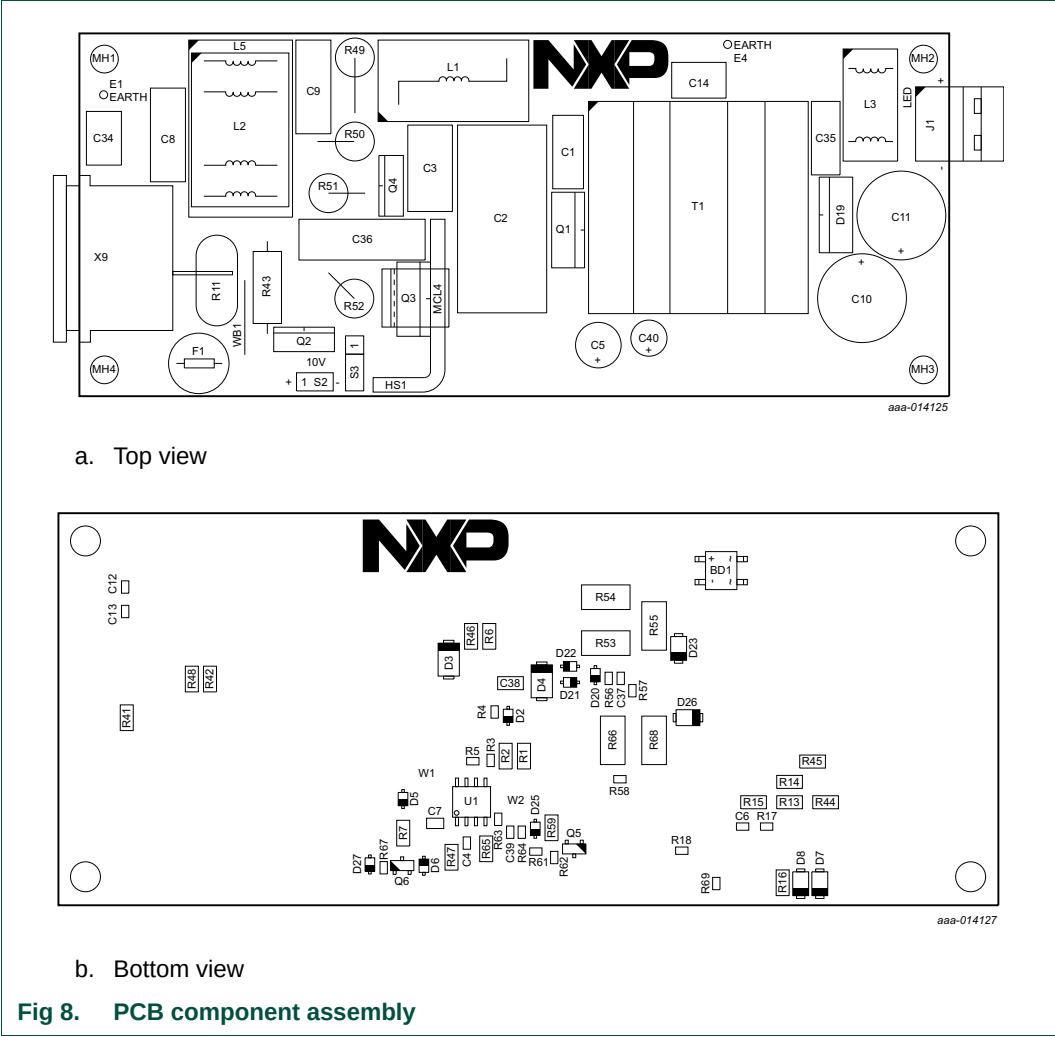
Reference	Description and values	Part number	Manufacturer
F1	fuse; 2 A; slow-blow	38312000000	Littelfuse
HS1	heat sink; 24 mm x 10 mm; aluminum: 2.0 mm	-	-
HS1_insulator	thermal insulator between heat sink and MOSFET Q3	53-77-9ACG	Aavid
J1	connector; terminal block; 5.08 mm	1508060000	Weidmüller
L1	inductor; differential mode; 696 μ H; 2 A	750312186	Würth Elektronik
L2	inductor; not mounted; common-mode; 47 mH; 450 mA	B82731T2451A020	EPCOS
L3	inductor; common-mode; 47 μ H; 2 A	744841247	Würth Elektronik
L5	inductor; common-mode; 47 mH; 700 mA	B82732F2701B001	EPCOS
MCL1	terminal block; BL 5.08/2	1716320000	Weidmüller
MCL2; MCL3	EMI suppression bead; 12 Ω at 25 MHz	2673000501	Fair-Rite
MCL4	Heat sink clip	TRMC-1	Kang Yang
MCL11	not mounted	-	-
Q1	MOSFET-N; 710 V; 7 A; TO-220	STP8N65M5	ST Micro Electronics
Q2	transistor; NPN; 400 V; 500 mA; TO-126	KSC2752OSTU	Fairchild
Q3	MOSFET-N; 500 V; 3.1 A	IRFI830GPBF	Vishay
Q4	MOSFET-N; 600 V; 7 A	SIHU7N60E-GE3	Vishay
Q5	transistor; NPN; 30 V; 1 A	NSS30101LT1G	ON Semiconductor
Q6	transistor; NPN; 65 V; 100 mA	BC846	NXP Semiconductors
R1; R2	resistor; 0.91 Ω ; 1 %; 250 mW; 1206	RCWE1206R910FKEA	Vishay
R3	resistor; 5.6 k Ω ; 1 %; 63 mW; 0603	ERJP03F5601V	Panasonic
R4	resistor; 39 Ω ; 1 %; 63 mW; 0603	ERJ3GEYJ390V	Panasonic
R5	resistor; 15 k Ω ; 1 %; 100 mW; 0603	RC0603FR-0715KL	Yageo
R6	resistor; 180 k Ω ; 1 %; 500 mW; 1206	CRGH1206F180K	TE Connectivity
R7	resistor; 27 Ω ; 1 %; 250 mW; 1206	ERJ8GEYJ270V	Panasonic
R11	varistor; 320 V; 170 pF	V320LA10P	Littelfuse
R13; R14; R15	resistor; 150 k Ω ; 1 %; 250 mW; 1206	RE1206DR-07150KL	Yageo
R16	resistor; 3.9 k Ω ; 1 %; 250 mW; 1206	RC1206JR-073K9L	Yageo
R17	resistor; 47 k Ω ; 1 %; 100 mW; 0603	RC0603FR-0747KL	Yageo
R18	Resistor; 390 k Ω ; 1 %; 100 mW; 0603	RC0603FR-07390KL	Yageo
R41	resistor; 120 k Ω ; 1 %; 250 mW; 1206	RC1206FR-07120KL	Yageo
R42	resistor; not mounted	-	-
R43	resistor; fusible; 4.7 Ω ; 5 %; 2 W; MFP2	MFP2-4R7 JI	Welwyn Components
R44; R45; R47	resistor; 0 Ω ; 1 %; 250 mW; 1206	RC1206FR-070RL	Yageo
R46	resistor; not mounted; 180 k Ω ; 1 %; 500 mW; 1206	CRGH1206F180K	TE Connectivity
R48	resistor; not mounted	-	-
R49; R50	resistor; 470 Ω ; 5 %; 3 W; ROX; THT	ROX2SJ470R	TE Connectivity
R51; R52	resistor; 390 Ω ; 5 %; 2 W; ROX; THT	ROX2SJ390R	TE Connectivity

Table 5. SSL5301DB1204 demo board bill of materials

Reference	Description and values	Part number	Manufacturer
R53; R54	resistor; 56 Ω ; 1 %; 2 W; 2512	CRGH2512J56R	TE Connectivity
R55	resistor; 4.7 Ω ; 5 %; 2 W; 2512	RC2512JK-7W4R7L	Yageo
R56	resistor; 33 k Ω ; 1 %; 100 mW; 0603	RC0603FR-0733KL	Yageo
R57	resistor; 300 Ω ; 1 %; 100 mW; 0603	CRCW0603300RFKEA	Vishay
R58	resistor; 470 Ω ; 5 %; 100 mW; 0603	RC0603JR-07470RL	Yageo
R59	resistor; 18 Ω ; 1 %; 500 mW; 1206	CRCW120618R0FKEAHP	Vishay
R61	resistor; 300 k Ω ; 5 %; 100 mW; 0603	ERJ3GEYJ304V	Panasonic
R62	resistor; 1.5 M Ω ; 5 %; 100 mW; 0603	ERJ3GEYJ155V	Panasonic
R63; R64	resistor; 820 Ω ; 5 %; 100 mW; 0603	ERJ3GEYJ821V	Panasonic
R65	resistor; 0 Ω ; 1 %; 250 mW; 1206	CRCW12060000Z0EAHP	Panasonic
R66; R68	resistor; 7.5 Ω ; 1 %; 2 W; 2512	RHC2512FT7R50	Stackpole Electronics
R67; R69	resistor; 47 k Ω ; 5 %; 100 mW; 0603	RC0603JR-0747KL	Yageo
S2	header; 2-way of 36-pin part; pitch = 2.54 mm	SL11 124 36G	Fischer
S3	header; 3-way of 36-pin part; pitch = 2.54 mm	SL11 124 36G	Fischer
T1	transformer; PQ2620	750314763	Würth Elektronik
U1	SSL5511T	SSL5511T	NXP Semiconductors
WB1	wire bridge; 0.8 mm; pitch = 10.16 mm	923345-04-C	3M
X9	connector; mains inlet	771W-BX2-01	Qualtek

10. PCB layout

10.1 Component assembly



10.2 Signal layout

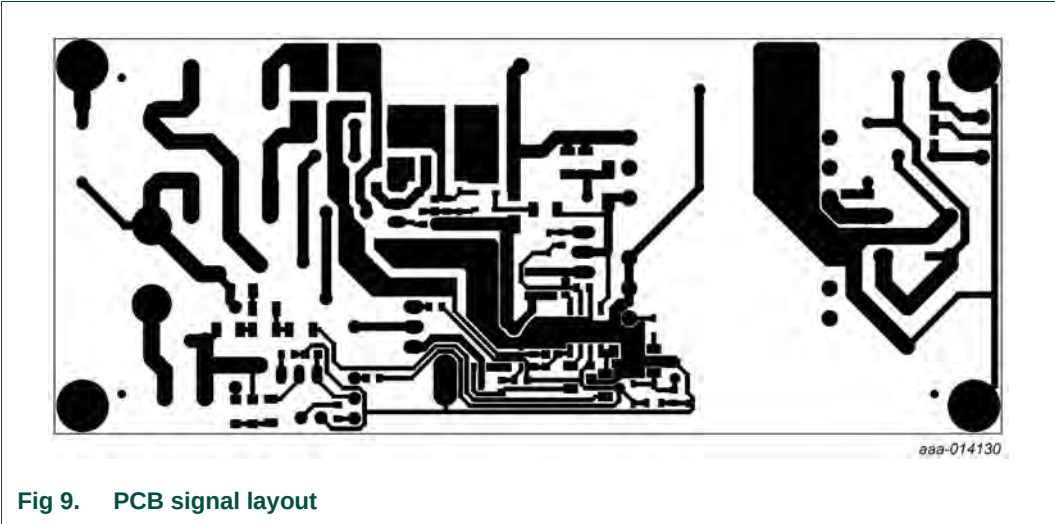


Fig 9. PCB signal layout

11. Transformer specifications

11.1 Flyback transformer specification

A PQ2620 core/bobbin is used for the flyback converter.

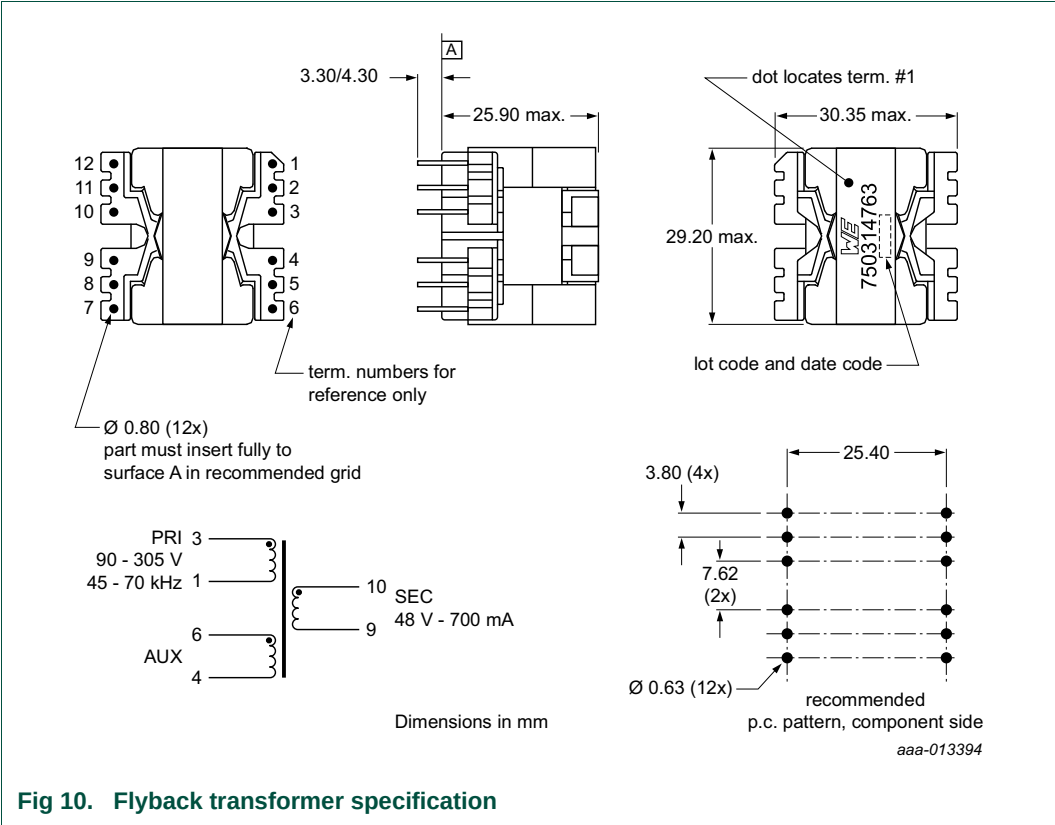


Table 6. Electrical specifications*All values are specified at 25 °C unless otherwise specified.*

Parameter	Value	Conditions
DC resistance (3-1)	707 mΩ; ±10 %	
DC resistance (10-9)	135 mΩ; ±10 %	
DC resistance (6-4)	96 mΩ; ±10 %	
primary inductance (3-1)	680 μH; ±10 %	100 mV; 10 kHz
leakage inductance (3-1)	2 μH nominal; 5 μH maximum	short 10-9 and 6-4; 100 mV; 100 kHz
primary saturation current	2.7 A	
turns ratio 3-1: 10-9	2.8: 1; ±1 %	
turns ratio 3-1: 6-4	3.5: 1; ±1 %	

12. Errata

12.1 EMI performance shows increased peaking at 20 MHz with PE connected

When the mains Protective Earth (PE) is connected, the EMI performance decreases at 20 MHz. The performance decreasing is not an issue in the present SSL5301DB1204 demo board because PE is not connected.

When PE is connected, mount C34 = 2.2 nF in the application.

12.2 Start-up behavior of V_{CC}

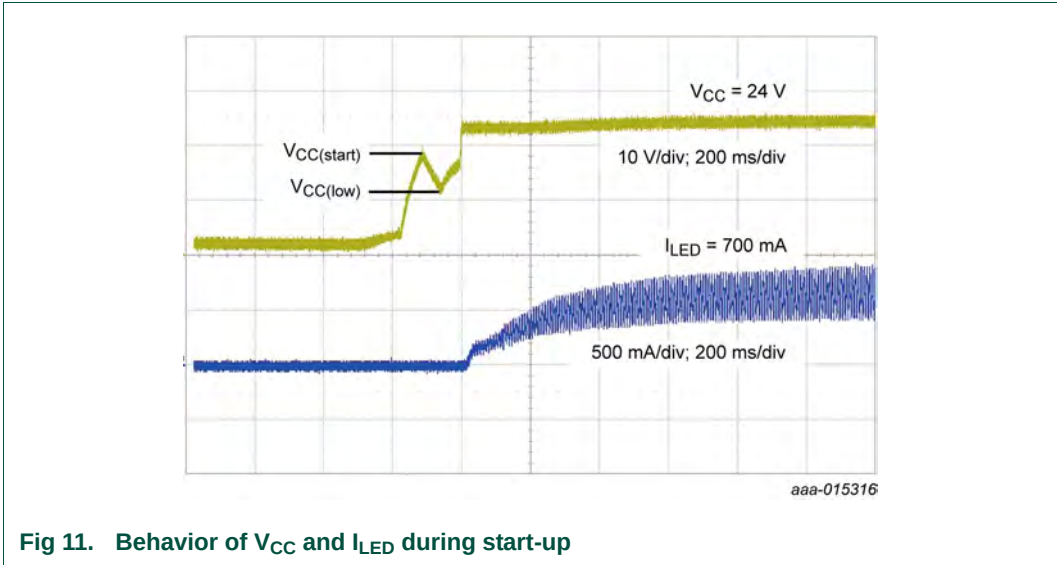


Fig 11. Behavior of V_{CC} and I_{LED} during start-up

12.3 Flyback transformer construction and wire diameter

Table 7. Flyback transformer construction

Wire	Description
1 st primary	21 turns of bifilar wire; $\varnothing = 0.2\text{ mm}$ copper
secondary	15 turns of TIW; $\varnothing = 0.4\text{ mm}$ copper
2 nd primary	21 turns of bifilar wire; $\varnothing = 0.2\text{ mm}$ copper
auxiliary	12 turns; $\varnothing = 0.4\text{ mm}$ copper

The secondary windings are sandwiched between the 1st and 2nd primary windings for low primary leakage inductance.

13. Abbreviations

Table 8. Abbreviations

Acronym	Description
EMI	ElectroMagnetic Interference
HF	High-Frequency
LED	Light-Emitting Diode
OCP	OverCurrent Protection
OTP	OverTemperature Protection
PE	Protective Earth
PF	Power Factor
PCB	Printed-Circuit Board
PFC	Power Factor Correction
PWM	Pulse Width Modulation
SSL	Solid-State Lighting
THD	Total Harmonic Distortion

14. References

- [1] **SSL5301T data sheet** — Mains dimmable controller for LED lighting
- [2] **AN11533 application note** — SSL5301 mains phase-cut dimmable LED driver

15. Legal information

15.1 Definitions

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For sales office addresses, please send an email to: salesaddresses@nxp.com

Date of release: 15 October 2014

Document identifier: UM10813